DEVELOPMENT OF A SIMULATOR FOR THE EVALUATION OF RIGID AND MOVABLE AIRCRAFT CONTROLS

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THESIS

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Development of a Simulator for the

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ABSTRACT

A simulator was constructed with two sets of aircraft controls; one set was movable and one set was rigid. The control output signals were integrated into an analog computer circuit to provide the desired aerodynamic characteristics. A repeatable, random input voltage to an oscilloscope was used as a basis for a tracking exercise in which the test subject, by manipulation of the control stick, attempted to cancel the random signal. A scoring method was devised which utilized an electronic counter and signal comparator to evaluate pilot performance with each of the four control sticks.

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ACKNOWLEDGMENTS

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I. INTRODUCTION

In dealing with airplanes that are to be flown by human pilots, it is obvious that the machine must be designed to match the man. The man-machine combination is a major factor that goes into making a complete aircraft system and therefore the man and the machine have to be matched to the fullest degree.

An aircraft, as most pilots are led to believe, is required to have controls that move in a certain direction and deflection to obtain a given control surface response. It was felt that in modern aircraft this control movement was unnecessary because rigid control sticks could be constructed by utilizing the present state of the art of electronics and of aircraft control systems.

On modern high speed aircraft, the forces required to move the control surfaces frequently exceed the physical capabilities of a human pilot and some form of power assist is necessary. In "fully powered" aircraft there is no direct force coupling between pilot's controls and the aerodynamic control surfaces. The pilot operates a controlling device which feeds signals; (e.g. electrical, mechanical, hydraulic,) into the control system. These type control systems are operational and there should be no difficulty in adapting a rigid stick to such aircraft.

A simulator was constructed to evaluate rigid control sticks by comparing them to similar movable conventional

sticks. The test subjects did not only evaluate the rigid sticks but their reaction and skill was also measurable and could be used to weigh their preference.

No reference to a non-movable control system could be found. References 1, 2, 3, and 4 used strain gage force commands from a stick to actuate the control servos directly, but the controls were still of a conventional movable type. Strain gages were considered to be the best device to generate a force signal by a rigid control stick.

In considering a method to evaluate such control sticks, it was felt that only a tracking problem was required and not one in which various instruments had to monitored. A decision was made to use an X - Y cathode ray oscilloscope as the primary reference instrument utilizing a repeatable, random input signal from a tape recorder as a tracking problem. The individual being tested was to use the rigid (or movable) control stick to generate a signal, properly amplified, to cancel out the random input signal by use of a summing amplifier. The combined signal would be visually displayed on the oscilloscope for a reference and would be used as a measurement of pilot ability and reaction.

II. SIMULATOR FACILITY

The simulator facility designed and built for this evaluation is composed of two oscilloscopes, two power supplies, an analog computer, an electronic counter, a low frequency function generator, a millivoltmeter, an Ampex tape recorder, a two channel Brush recorder, an electric timer, a cockpit environment housing, and interface equipment.

Figure 1 shows the overall view of the simulator cockpit environment housing which was constructed using a 96" x 34" base of heavy plywood and 2" x 4" frame on which was mounted a salvaged FJ ejection seat. A cover was constructed over a frame to create an aircraft cockpit environment. An oscilloscope was mounted in the area of the windscreen to give the required visual reference for the tracking problem. Figure 2 shows a partial internal view of the cockpit with the lower portion of the oscilloscope, pilot's seat and rigid stick visible.

The oscilloscope has a transparent grid over the scope which allows the individual being tested to correct for parallax by using the horizontal and vertical position knobs on the scope to center the signal pip under the mid grid lines.

A ventilator fan which is activated by the entrance door being closed was installed for the cooling of the simulator cockpit. In addition, a small 115 volt fan was mounted in the windscreen area for the purpose of cooling the main oscilloscope.

FIGURE 1
EXTERNAL OVERALL VIEW OF SIMULATOR

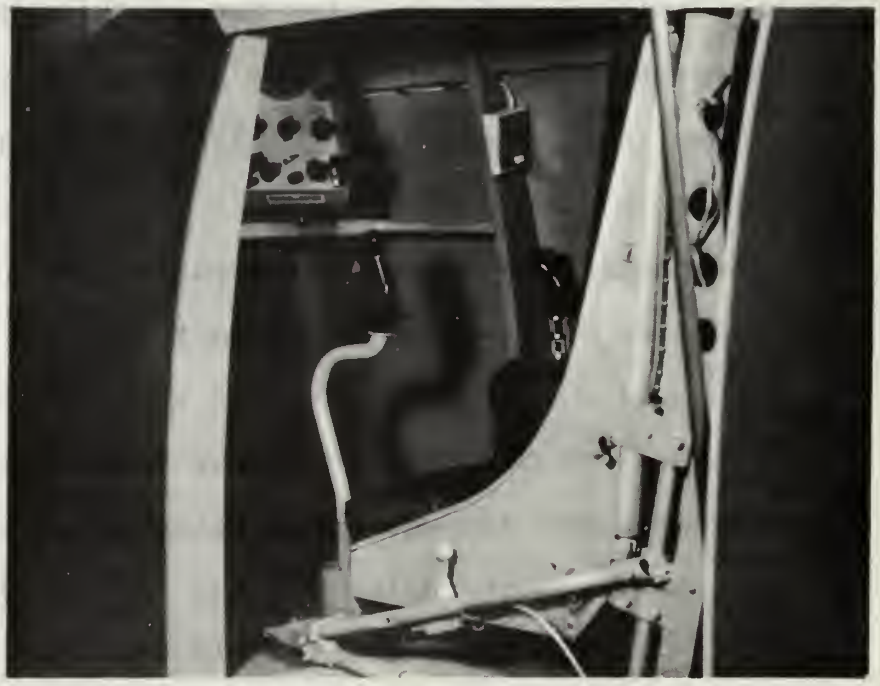

FIGURE 2
INTERNAL VIEW OF SIMULATOR COCKPIT

Two indicator lights, red and blue, were installed in the cockpit windscreen area beside the oscilloscope; the red light to indicate when the target pip was in the scoring area and the blue light to indicate when the electronic counter circuit was activated. Figure 3 shows the oscilloscope and indicator panel on which the scoring and counter lights are mounted.

The simulator has wiring installed for the connection of the four control units so that any stick, when plugged in, will be connected to the output terminals when the control stick selector switch on the patch panel of the simulator is in the corresponding position. See Figure 4.

The two 12-wire bundles from the stick selector switch are identical. One is routed to the hand stick arm rest and the other goes to the deck-mounted stick area. At the end of each wire bundle is a sixteen connector plug which has twelve positions (Figure 13) utilized as follows:

1. Common junction of strain gages (longitudinal)
2. Forward strain gage terminus (longitudinal)
3. Aft strain gage terminus (longitudinal)
4. Movable stick output (longitudinal)
5. Common junction of strain gages (directional)
6. Left strain gage terminus (directional)
7. Right strain gage terminus (directional)
8. Movable stick output (directional)
9. Plus five volts (longitudinal)
10. Minus five volts (longitudinal)
11. Plus five volts (directional)
12. Minus five volts (directional)

FIGURE 3

OSCILLOSCOPE AND INDICATOR PANEL

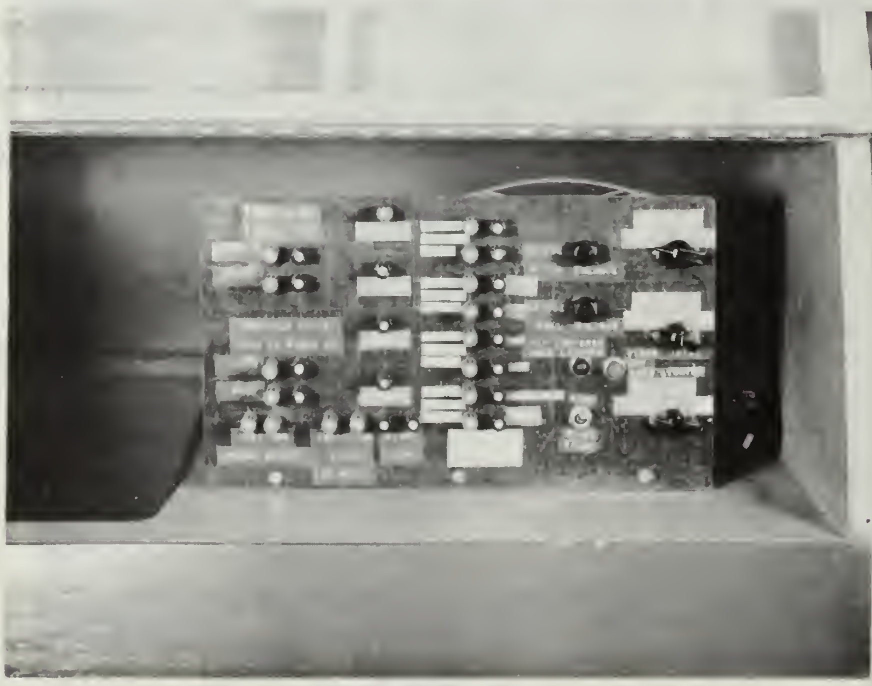

FIGURE 4

PATCH PANEL ON SIMULATOR

No rudder pedals or facsimile of rudder pedals were installed in the cockpit simulator for simplicity and because they are seldom needed in single engine jet aircraft in the cruise configuration.

A 115/6.3 volt transformer was installed to provide the proper power for the indicator lights on both the patch panel and the cockpit windscreen indicator panel.

The overall view of the simulator facility is shown in Figure 5 which displays some of the circuit wiring between the system components. The standard electronic components used for the simulator facility are listed in Appendix A.

FIGURE 5

VIEW OF SIMULATOR FACILITY

FIGURE 6

MOVABLE DECK-MOUNTED STICK

III. CONSTRUCTION OF CONTROL STICKS

Four different control sticks were constructed for use in the evaluation. Two of the sticks were made as a conventional movable type utilizing variable potentiometers as signal generators. The other two control sticks were constructed as rigid types and use strain gages in a Wheatstone bridge circuit as the signal generators.

One of the rigid sticks and one of the movable sticks were made as conventional deck-mounted types and the other two sticks were made into side-arm hand control units.

A. MOVABLE DECK-MOUNTED STICK

The major components of the movable deck-mounted stick were salvaged from a North American FJ aircraft. These parts, consisting of the stick proper, pitch and roll fulcrums, and lever arms, were mounted on an 18" x 27" x 3/4" plywood base. See Figure 6. The height of the stick from the base is 25 5/8" with a moment arm of 22" in pitch direction and moment arm of 16" in the roll direction. An artificial feel system was installed to develop a stick force in proportion to stick displacement simulating the control feel of a jet aircraft. Springs are mounted in the fore and aft direction and in the roll direction for approximation of an aircraft control feel. No bobweights were used in the system. Two variable potentiometers were mounted on the control unit, one to generate pitch signals and one to generate roll signals. The variable potentiometers are of the one turn type driven by a

1:4 ratio drive from the stick. The gearing between the stick position and the simulated control surface deflection is a linear relationship even though the majority of powered control systems employ a nonlinear gearing so that relatively greater stick deflection per surface deflection will occur at the neutral stick position. [Ref. 5]. Plus and minus five volts are the inputs to the potentiometers and the output signals are the simulated position indications of the elevator and aileron. These outputs become the inputs to the switching circuit shown in Figure 13, (for clarity, only the movable hand stick circuit is shown which is identical to the movable stick) and thence into the analog circuit shown in Figure 14.

The plywood base fits under the ejection seat in the cockpit simulator to provide a solid platform for the operation of the stick. The input and output wires are attached to a sixteen connector plug which was required for the rapid change of control sticks.

B. MOVABLE HAND STICK

The movable hand stick as shown in Figure 7 was mounted on a quarter inch aluminum box 3" x 4" x 14" which contains the roll variable potentiometer and the roll artificial feel springs. The pitch potentiometer, along with the pitch feel springs, is located externally and forward of the control box. The pitch and roll potentiometers have a 1:4 gear ratio with the output from a plus and minus five volt input being sent to the switching circuit, shown in Figure 13, and thence

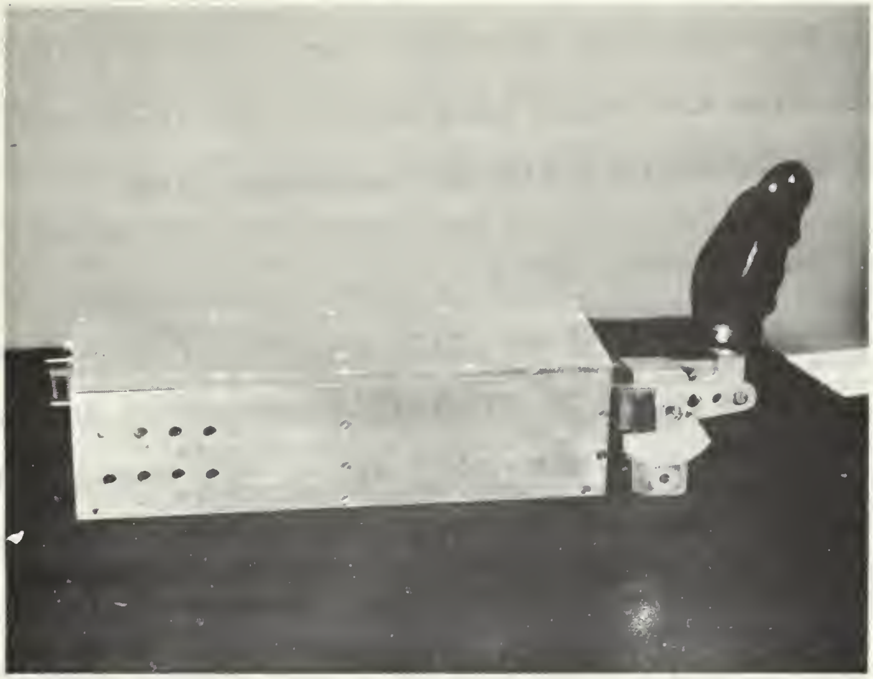

FIGURE 7
MOVABLE HAND CONTROL STICK

FIGURE 8
RIGID DECK-MOUNTED STICK

into the analog circuit, shown in Figure 14. As in the movable deck-mounted stick, the motion of the hand grip is linear in relation to the simulated control surface deflection. The control unit is mounted on Velcro fabric for a quick change capability with the rigid hand stick. The input and output wires are attached to a sixteen connector plug.

C. RIGID DECK-MOUNTED STICK

The rigid, deck-mounted stick was constructed from a salvaged helicopter stick by cutting it down to an equivalent size, as compared to the movable stick, and then mounting it on an aluminum flexure. See Figure 8. The flexure shown in Figure 11 was machined from one inch diameter 2024-T4 Alcoa aluminum stock. This material has an ultimate tensile strength of 68,000 psi and a yield strength of 47,000 psi at a temperature of 75° F. [Ref. 6].

It was desired to have the maximum bending stress of the flexure approximately one-half of the yield stress in order to provide the maximum possible signal, yet still be well within the yielding point of the 2024 aluminum. Assuming a moment arm of approximately two feet, figured from the top third of the control grip to the center of the flexure, and an applied force of 15 pounds, the moment becomes 360 inch-pounds. The formula

$$S_{max} = \frac{Mc}{I} = \frac{M}{bh^2/6}$$

was used to calculate the thickness h = .3 inches. An S_{max} of 24,000 psi and a 'b' of 1" was used for this calculation.

Four SR-4 strain gages, type FAB-25-12513, were attached as shown in Figure 10, by Eastman 910 cement and then waterproofed. The strain gages had gage factors of 2.07 ± 1%, resistances of 120.0 ± .2 ohms, and were designed to be temperature compensated for aluminum.

The strain gages were used as two resistances in a Wheatstone bridge that was energized with 10 volts. In this connection, the bending moment applied will cause the voltage changes in the two strain gages to be additive while canceling out the effects of a moment applied at right angles to the flexure. [Ref. 7]. The Wheatstone bridge arrangement is shown in Figure 13.

The flexure was pressed into a six inch square piece of 3/4" aluminum which was then mounted on the plywood base 18" x 27" x 3/4". A strain gage guard was constructed of three inch aluminum thin-walled tubing and mounted around the flexure area to protect the delicate strain gages and wiring from damage. The attached wires were connected to a sixteen connector plug for quick-change ability.

D. RIGID HAND CONTROL STICK

The rigid hand control stick was mounted on a quarter inch aluminum control box 3" x 4" x 14" similar to that of the movable hand stick. See Figure 9. The aluminum flexure, as shown in Figure 12, was constructed of identical material as the rigid deck-mounted flexure but the thickness of the flexure was reduced to .15" which resulted in a maximum stress of 25,000 psi computed for a force of fifteen pounds on a

moment arm of six inches. This compares closely to the 24,000 psi of the rigid stick maximum stress computed using a force of fifteen pounds on a 24 inch moment arm.

Strain gages identical to the ones on the rigid deck mounted stick were attached and similar wiring, plugs, and circuits were used. For clarity, Figure 13 shows only the switching and Wheatstone bridge circuits for the rigid hand stick and not the rigid deck-mounted stick.

The hand grips used for the hand controllers were made of an epoxy mixture of five parts APCO 210 Resin and one part APCO 180 Hardener with carbon lampblack added for color. The knurled sections of the handles were cast in molds shown in Figure 10, which had been made using a clay hand grip model.

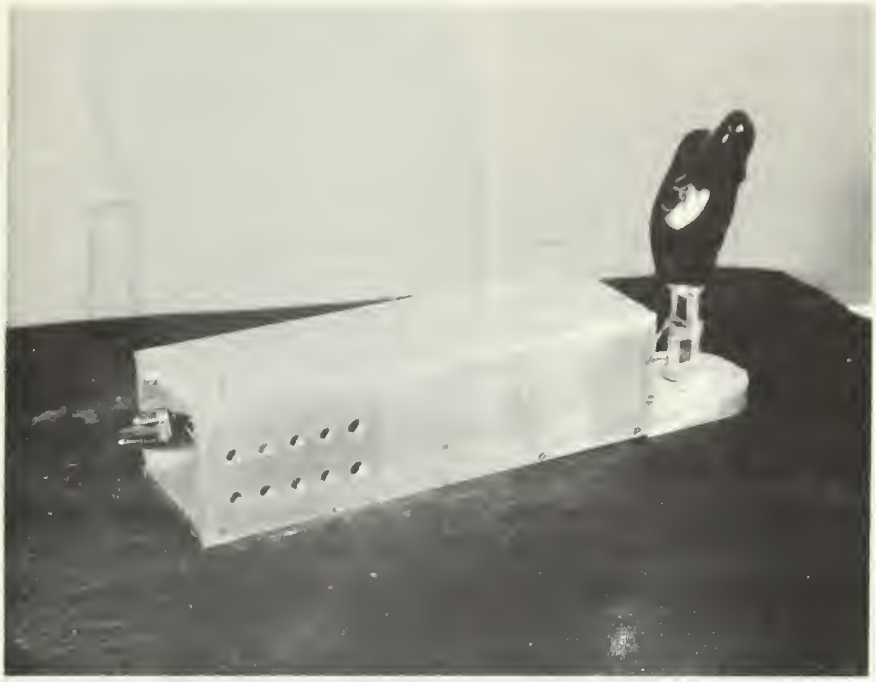

FIGURE 9
RIGID HAND CONTROL STICK

FIGURE 10
HAND GRIP MODEL AND MOLDS

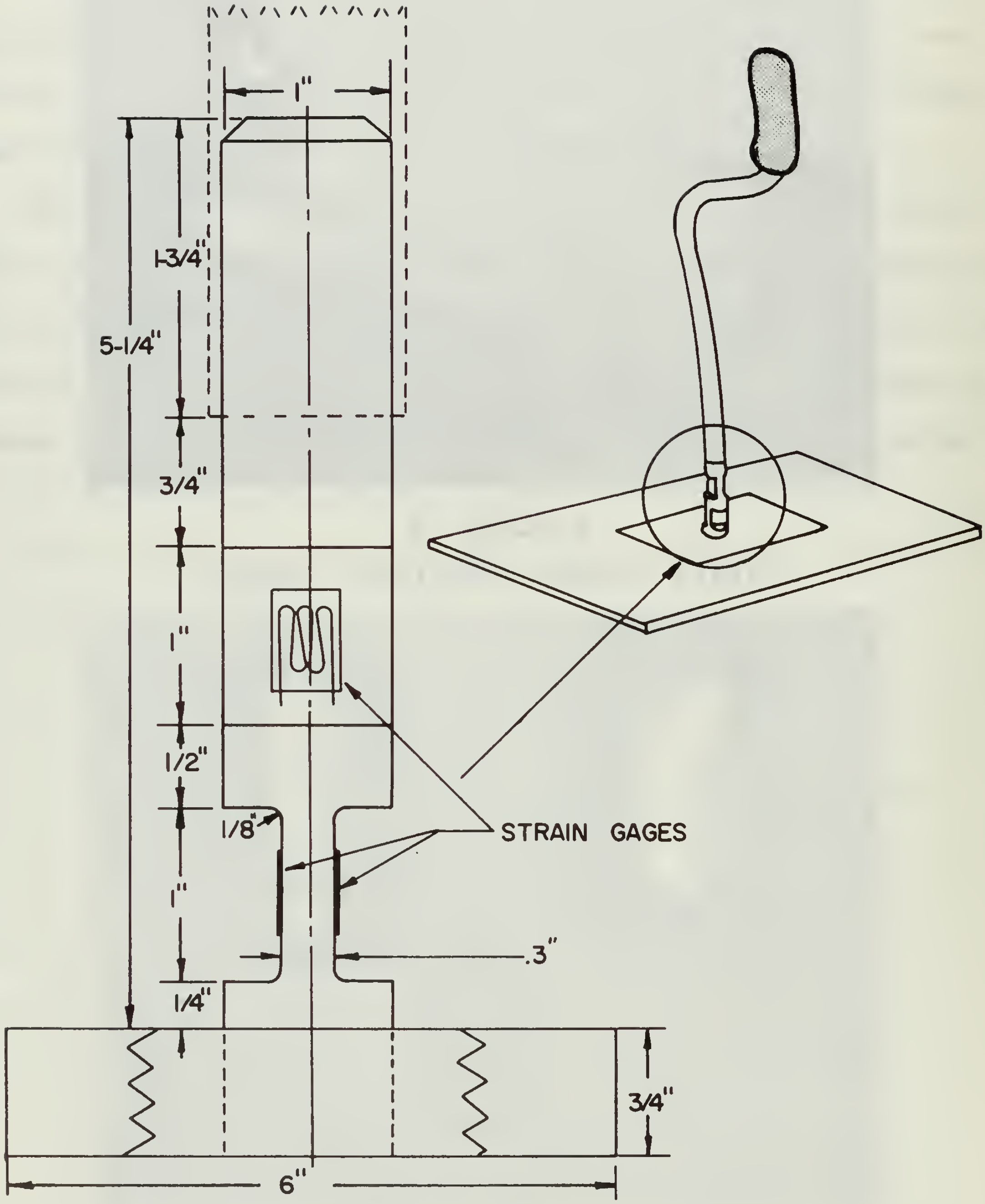

FIGURE 11

RIGID STICK FLEXURE INSTALLATION

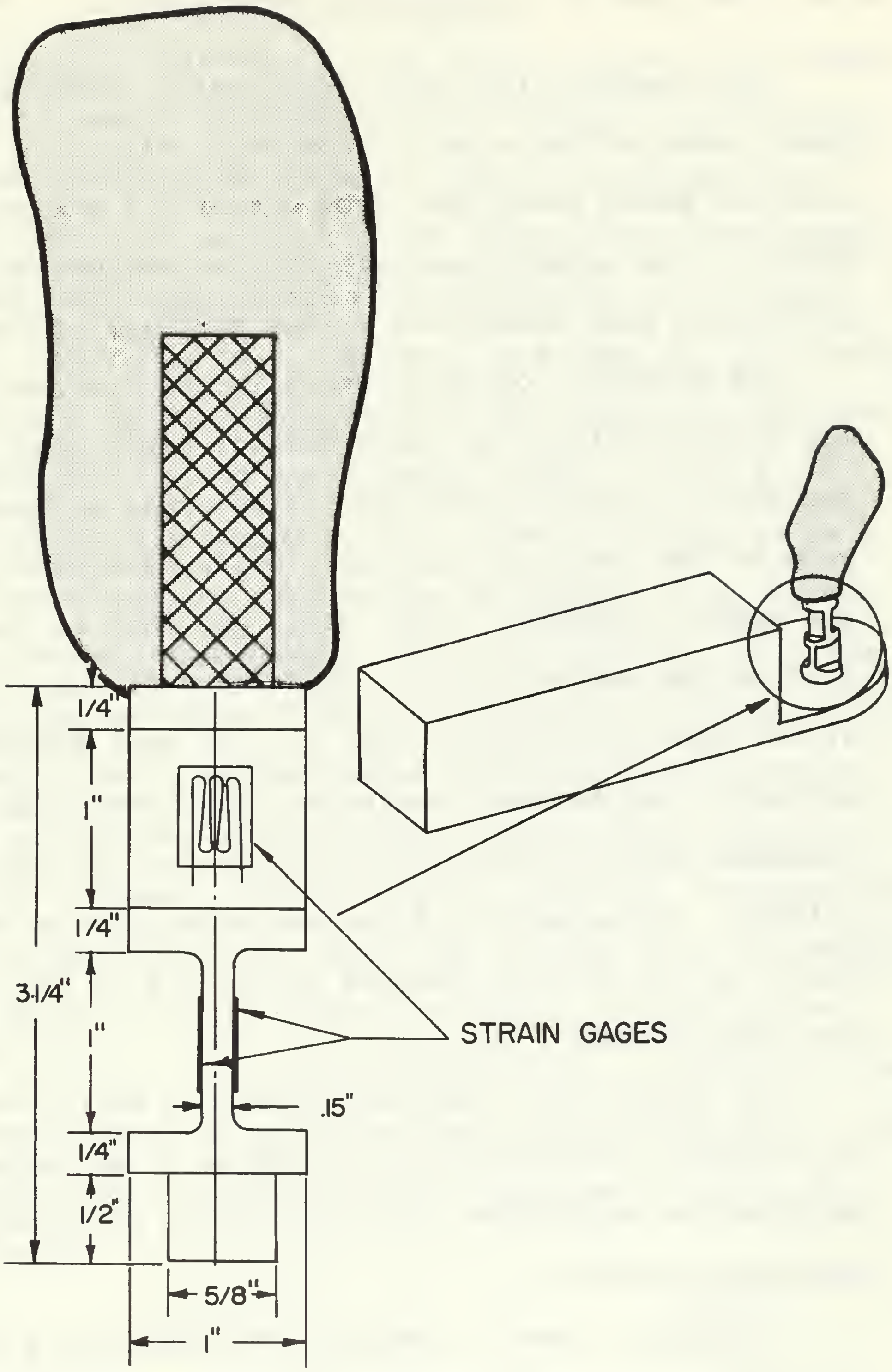

FIGURE 12

RIGID HAND STICK FLEXURE INSTALLATION

IV. ANALOG COMPUTER CIRCUIT

The inputs to the Pace TR-10 Analog Computer are from the patch panel of the simulator shown in Figure 4. The outputs from the patch panel come from either the variable potentiometers of the movable controls or from the output junctions of the strain gage Wheatstone bridge circuits of the rigid stick.

The selection of which stick inputs are used depends on the switch position on the simulator patch panel and also on the output wiring of the panel. In order to change the outputs of the simulator the patch cords have to be switched to the proper terminals on the panel and then to the input position on the analog computer using correct input resistors (2,000 ohms for rigid sticks, 100,000 ohms for movable sticks). The feedback resistors also have to be changed as required (400,000 ohms for rigid sticks, 100,000 for movable sticks). These values of the resistors give an amplification factor of one for the movable sticks and of two hundred for the rigid sticks.

The signals are then run through an additional amplifier to increase the amplitude by a factor of ten after which they go into the respective circuits for the longitudinal and directional control.

The circuit used to amplify the signals and simulate an aircraft is shown in Figure 14. The longitudinal circuit is an approximation of the dynamics of an F4-type aircraft flying at .9 Mach at sea level. Figure 16 shows the output of the

analog computer after a step longitudinal input (elevator) is introduced into the system. The output is considered to be the pitch angle θ effected by the dynamic short period mode. In the short period approximation the airspeed remains constant, and therefore an elevator input results only in a change in the pitch angle, θ. The magnitude of this change depends on the length of time the step input is actuated. In addition, the change in θ, as shown in Figure 16, will remain in the circuit until removed due to the lack of an airspeed or altitude change with any elevator input. [Ref. 8].

The directional analog circuit shown in Figure 14 is a modified approximation of a stable aircraft. In a conventionally controlled aircraft, the pilot commands roll rate directly, but Reference 9 implies pilots prefer an aircraft simulator to have a system where aileron commands bank instead of roll rate. This system is one in which the pilot has to hold a steady aileron force to maintain a steady bank angle. In this simulator, when the aileron force is removed, the bank angle not only stops, but slowly returns to the original position. This was necessary due to the lack of any directional reference other than the oscilloscope grid. Figure 17 shows the directional angle response to a step of aileron angle.

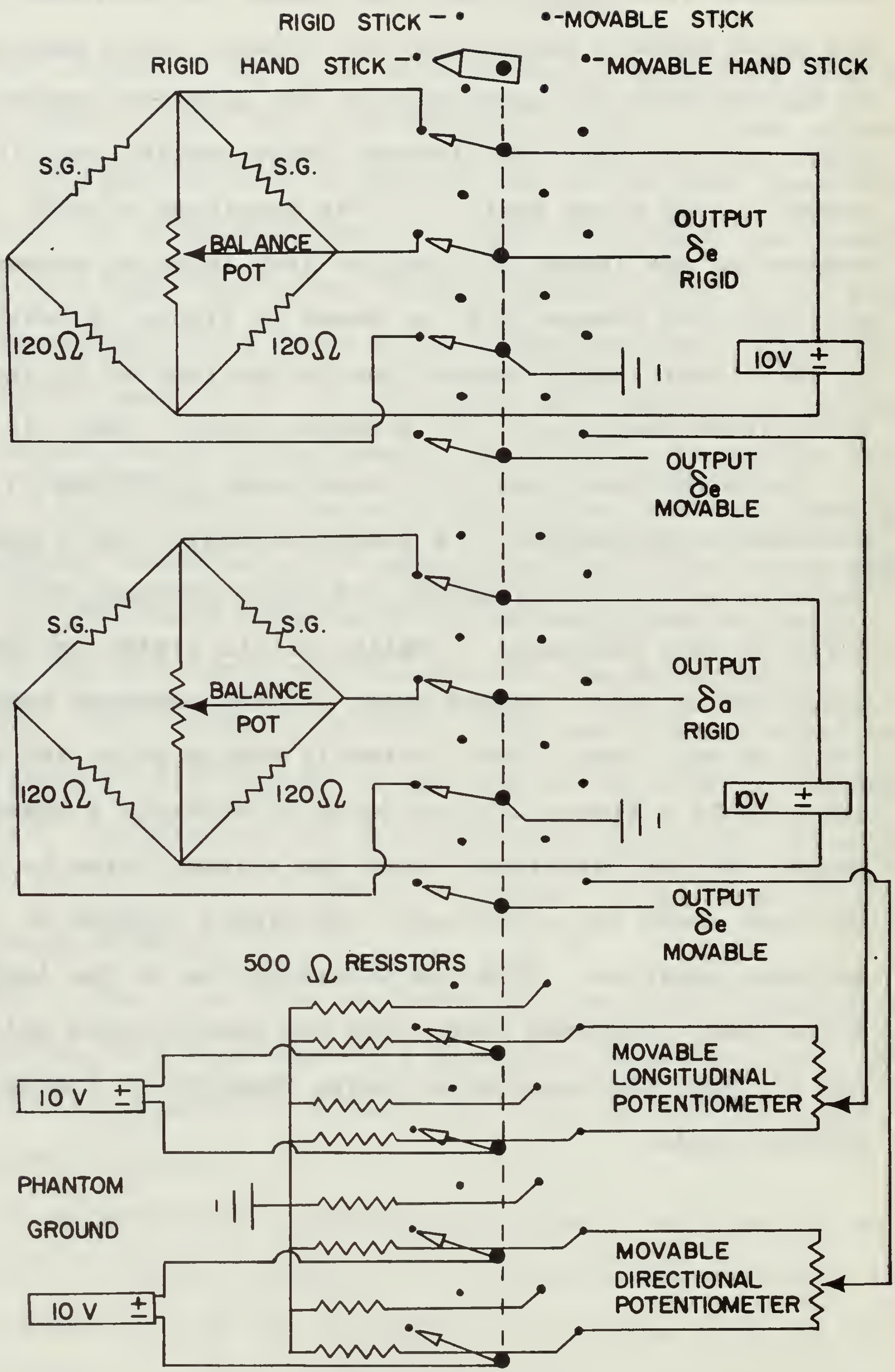

FIGURE 13

WHEATSTONE BRIDGE AND SWITCHING CIRCUIT

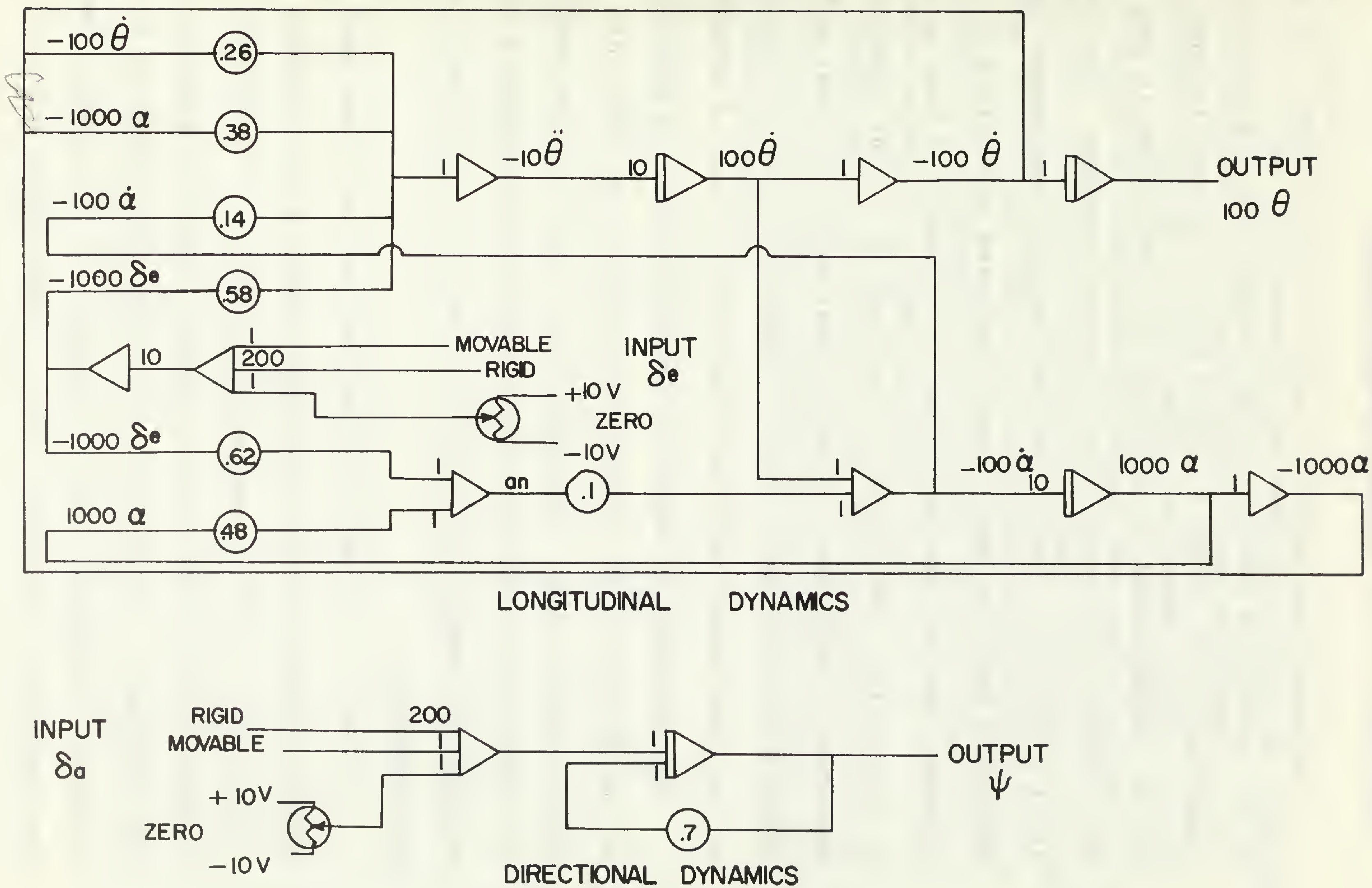

FIGURE 14. ANALOG COMPUTOR CIRCUIT

V. ANALOG TIMER CIRCUIT

The operations principal used in the simulator is that the pilot, using his control stick, cancels out the pre-recorded taped inputs to center a signal pip on an oscilloscope. Scoring is accomplished by measuring the error signals and timing the duration of errors below a pre-set maximum. The longitudinal signals and the directional signals are summed independently and then sent through separate amplifiers to increase the voltage magnitudes by a factor of ten, as shown in Figure 15. The signal is now sent to a sign changing amplifier. Both the original signal and the signal with the changed sign are sent through diodes which allow current flow in only one direction when a selected voltage is exceeded.

The increase in magnitude of the voltage is required due to the diodes which require a minimum of one-half volt to allow current flow. The additional sign changing amplifier is necessary so that both the plus and minus signals will trigger the comparator which is biased for signals of only one polarity.

A bias of -.5 volts was patched to the output side of the diode tie panel so that when any summed signal exceeds -.5 volts (after which it was multiplied by 10) the diodes allow current flow to the analog computer signal comparator input 1N1 terminal. An input of -.75 volts is patched to the 1N2 terminal to provide the bias signal for the signal comparator. The input of -.75 volts is not a fixed value, but is a

variable one which can be changed by the simulator operator to adjust the size of the scoring area on the simulator oscilloscope.

The relay, activated by the comparator, has an oscillator input (producing a 10 hertz signal) and an output to the electronic counter so that when the summed signals (either directional or longitudinal) exceed the specified amount, the oscillator signal to the counter ceases. The relay also activates an indicator light in the simulator to advise the individual being tested that the signal pip is within the scoring square, as shown in Figure 15.

A stop-start switch was added to the circuit, as shown in Figure 15, to permit the arming of the timing circuit during the scoring period.

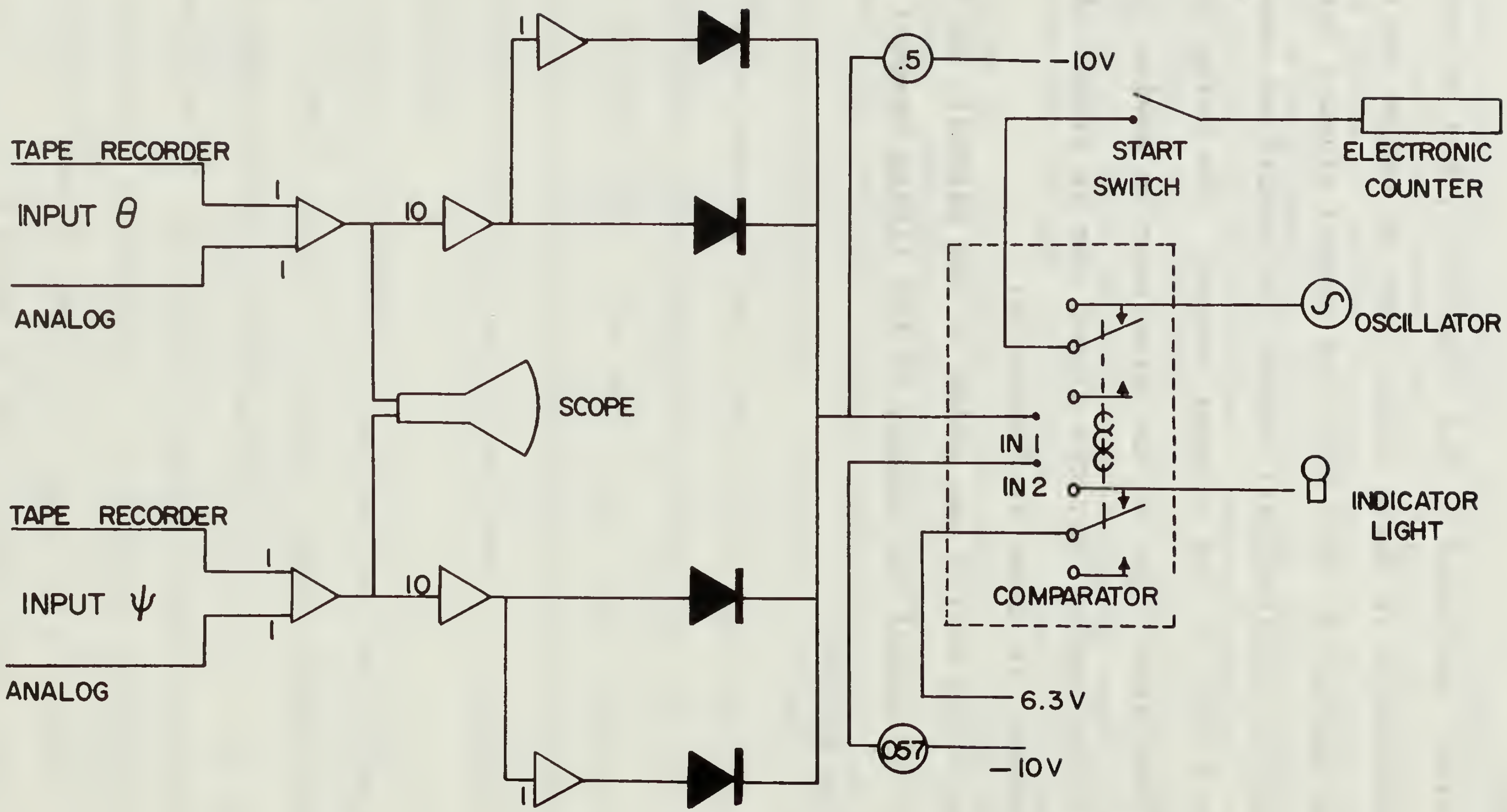

FIGURE 15

TIMING CIRCUIT

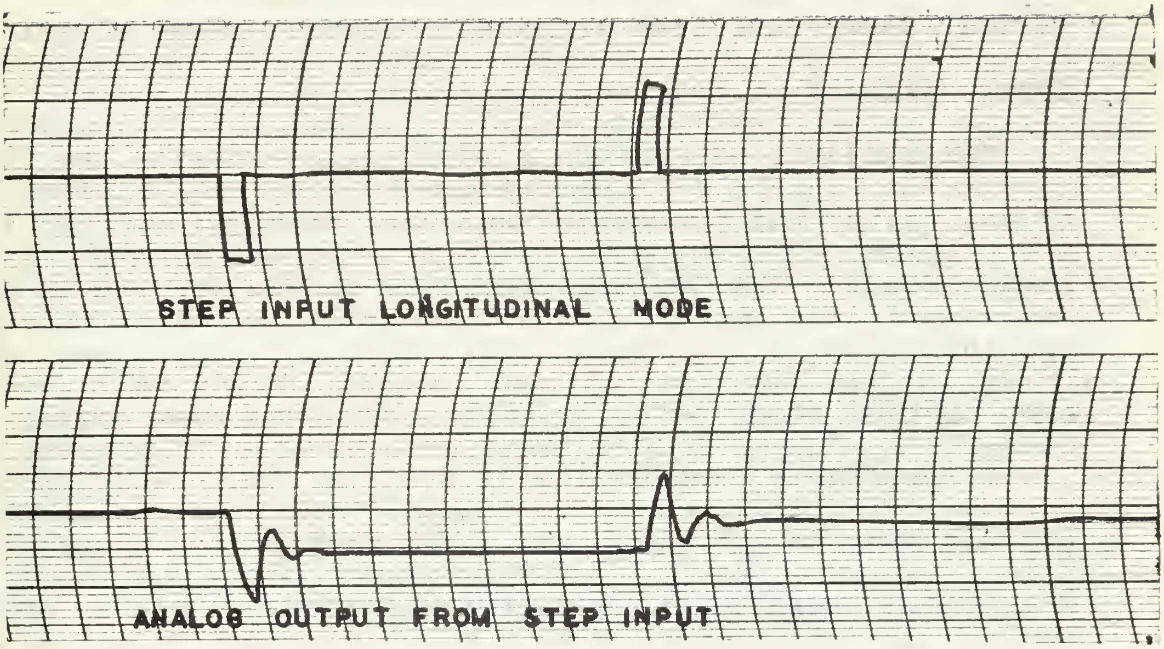

FIGURE 16

ANALOG COMPUTER RESPONSE (LONGITUDINAL)

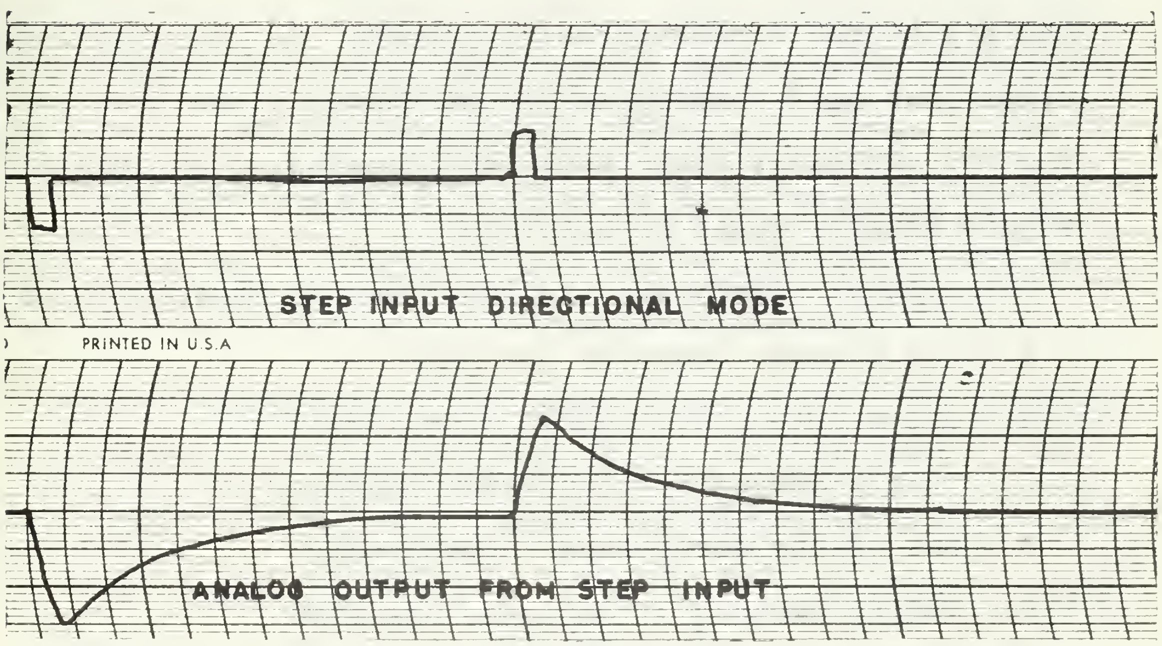

FIGURE 17

ANALOG COMPUTER RESPONSE (DIRECTIONAL)

VI. TESTING PROCEDURE

The subjects used in the preliminary evaluation tests had varied backgrounds such as Naval Aviators, Naval Flight Officer, private pilots, and non-pilots.

The subjects were given a short talk covering the purpose of the tests, the procedures and the interpretation of the rating scale. The testing procedure chosen was one in which the individual being tested would have a learning period on each control stick prior to being scored on that stick.

A repeatable, random signal from the tape recorder output was sent to the simulator oscilloscope (see Figure 15) as a tracking exercise. The person being tested was to move the control stick to position the signal pip into the center of the oscilloscope grid. This movement of the stick would cancel out the taped input signal, resulting in a centered signal pip on the simulator oscilloscope. If the signal pip was within one half centimeter of the center (less than .05 v.) the red indicator light would be illuminated and the electronic counter would be activated.

The input signal for the test run was programmed as follows:

A. Two minutes centered position

B. One minute longitudinal signal only

C. Thirty seconds of centered position

D. One minute directional signal only

E. Thirty seconds of centered position

F. One minute combined longitudinal and directional signal

G. Two minutes of centered position

H. Three minutes of combined longitudinal and directional signal to be used for scoring purposes.

The first centered position of the input signal permitted the individual being tested to become familiar with the motion of the stick, the scoring zone of the stick, and to reposition the centered position of the signal.

The testee was given a learning signal for longitudinal, directional and a combination of both prior to the scoring period. The thirty second period of centered signal was for the purpose of allowing the test subject to become oriented prior to the new signal input.

Identical signals were used for all four sticks, so that one series of tests would be no more difficult than another. The scoring signal was taped from a motion of the stick in a random motion by a non-pilot. All of the signals remained within the face of the oscilloscope. The scoring signal was neither smooth nor easily centered so that scoring deviations would give an adequate comparison of control sticks.

A permanent record of the scoring runs was obtained by means of a Brush Recorder using electric pen signal marking. A copy of a typical scoring run is shown for both longitudinal and directional axes in Figures 18 and 19 respectively. In both figures the random input signal was recorded on one channel while at the same time the resultant error signal was recorded on the other channel. This allowed the person tested the capability of comparing the recordings of the four different units.

The person tested filled out the questionnaire appearing in Appendix B, in which was listed experience in aircraft type such as: single or multi engine, carrier or non-carrier, yoke or stick controls, etc.

The persons tested also filled out a Cooper Rating for the four control units tested. Reference 10 is the standardized rating system that was devised by Cooper, a NASA Research pilot, to give both an adjective and numerical rating (from one to ten) to aircraft controls and control systems. See Appendix C.

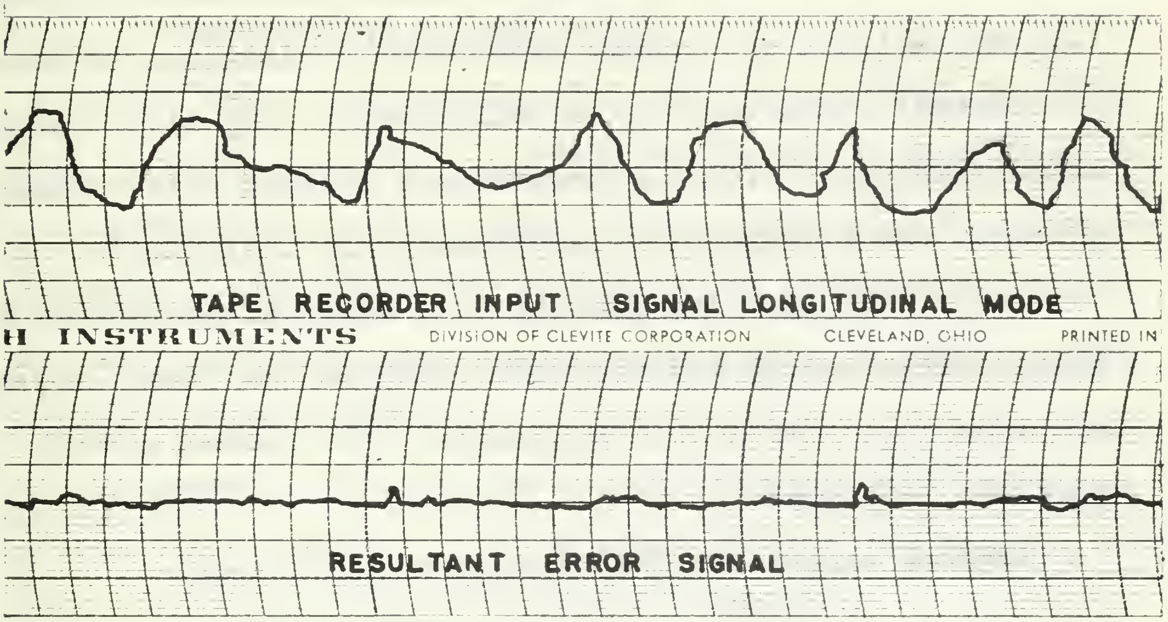

FIGURE 18

TYPICAL SCORING RUN (LONGITUDINAL)

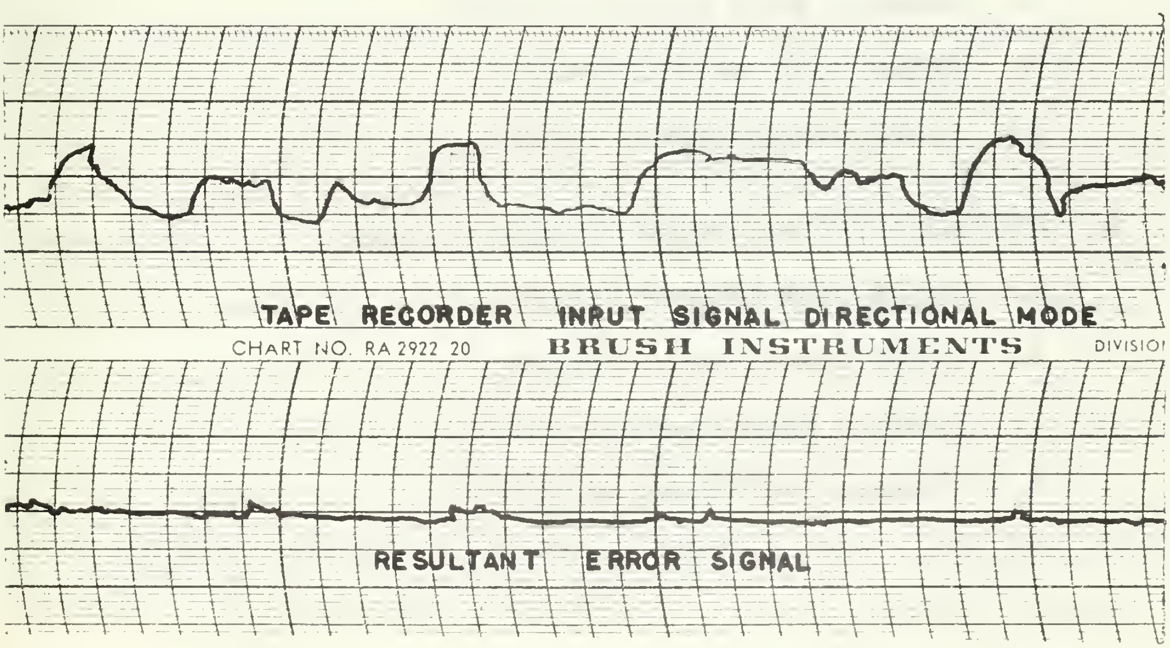

FIGURE 19

TYPICAL SCORING RUN (DIRECTIONAL)

VII. TEST RESULTS

Only a token number of personnel have been tested at the time of this writing. A limited number were tested to ascertain the ability to conduct meaningful evaluations of both the control units and of the individuals. Any alterations deemed necessary from the preliminary testing will be made prior to the testing of a large number of individuals.

One of the specific results that was noticeable from the small number tested was the fact that, as the tests progressed from one control unit to another, the testee's skill generally improved.

General results of the tests were as follows:

A. ORDER OF TESTS GIVEN

1. Movable Deck-Mounted Stick
2. Movable Hand Control Stick
3. Rigid Deck-Mounted Stick
4. Rigid Hand Control Stick

B. CONTROLS IN THE ORDER OF BEST SCORES

1. Rigid Deck-Mounted Stick
2. Rigid Hand Control Stick
3. Movable Hand Control Stick
4. Movable Deck-Mounted Stick

C. CONTROLS IN THE ORDER OF PREFERENCE

1. Rigid Hand Control Stick
2. Rigid Deck-Mounted Stick
3. Movable Deck-Mounted Stick
4. Movable Hand Control Stick

Other test results show that the input signal from the tape recorder provided a sufficient degree of difficulty so that proper deviation of test scores resulted. It is admitted that the movement of the target pip is extremely rapid and sometimes jerky but this was necessary to prevent test scores of almost 100%.

In general, the personnel tested showed rapid adaption to the rigid controls. It is apparent from the results that motion is unnecessary for aircraft controls.

A complete list of scores and pilots' backgrounds and control preferences are shown in Appendix D and Appendix E.

VIII. CONCLUSIONS AND RECOMMENDATIONS

The simulator facility developed for the rigid stick evaluation operated extremely well during the preliminary tests. The rigid control units worked so well that they were, in general, preferred over the more conventional type of movable controls. It is possible, since these units were so different from the normal controls, that the tested individuals had a tendency to favor them because of the novelty factor. Additionally, the rigid sticks were evaluated last in the series and therefore the preliminary test results may be biased due to the test subjects' becoming familiar with the simulator operation.

The use of the rigid control stick, especially the hand type controller, would be an ideal type to mount on an aircraft console, for use as a secondary controller. This would be available to be used when an electric flight system or "fly-by-wire" mode is operating. The rigid hand controller under high "g" conditions appears to be a more effective and efficient control than the typical stick. The weight and size penalty of such an installation would be negligible.

The rigid control units could also be used as an input to the auto-pilot in the majority of aircraft now in use.

Some refinement in the movable controls should be made before large scale evaluations are conducted. The major changes needed are as follows:

1. Alter the movable hand controller for better feel in the pitch system.

2. Change the one turn potentiometers now used to a more precision potentiometer.

3. Provide a breakout-force simulation for all control sticks. This could be done by using four diodes biased to a calculated voltage, dependent on the breakout force desired, which would activate a relay when the biased voltage was exceeded. The diode bias voltage would also have to be patched to a summing amplifier as a minus voltage to be subtracted from the control signal input to prevent a relatively large initial signal from being sent to the analog circuit. This system would work equally well with both the movable and the rigid sticks but to use this system would require additional analog computer circuitry.

4. Provide an automatic timer control for the scoring run vice the manually operated switch installed for the preliminary tests.

5. Provide a better visual display for the simulator tracking problem. A larger oscilloscope with the capability to display an horizon line would be a great improvement.

The rigid and movable sticks can be utilized as a classroom instructional aid for structures (strain gages under dynamic loads), flight dynamics (visual response of aircraft equation dynamics), and automatic control systems (visual response of various feedbacks).

It is further recommended that investigation be made in the field of flying qualities of different aircraft, of pilot response technique, and of the rigid stick utilizing the simulator developed in this project in accordance with the procedures used in Reference 11.

APPENDIX A

LIST OF EQUIPMENT UTILIZED

1. Two Channel Electric Recorder

    Brush Electronics

2. Low Frequency Function Generator, Model 202A

    Hewlett-Packard

3. Digitec D. C. Millivoltmeter

    United System Corp.

4. Model 130 A Oscilloscope

    Model 120 A Oscilloscope

    Hewlett-Packard

5. Universal Eput and Timer

    Berkeley Division Beckman's

6. Pace Trlo Analog Computer, Model 7350

    Electronic Associates, Inc.

7. Lab-Chron 115 v. 60 cps Timer

    Laboratory Industries, Inc.

8. Power Supply (two) Model 3569 15/30 v.

    System Research Corp.

APPENDIX B

FIXED AND MOVABLE AIRCRAFT CONTROL SIMULATOR

QUESTIONNAIRE

Test Number ___

TYPE EXPERIENCE		FLIGHT HOURS
MILITARY PILOT	________	________
PRIVATE PILOT	________	________
FLIGHT OFFICER	________	________
NON PILOT	________	________

CHECK TYPE AIRCRAFT IN WHICH MOST EXPERIENCE

MULTI ENGINE	________	JET	______
SINGLE ENGINE	________	PROP	______
CARRIER TYPE	________	YOKE	______
NON CARRIER	________	STICK	______
PRIVATE A/C	________		
HELICOPTER	________		

RESULTS

	COOPER RATING	SCORE
MOVABLE STICK	________	_____
MOVABLE HAND STICK	____	_____
FIXED STICK	________	_____
FIXED HAND STICK	____	_____

ORDER OF PREFERENCE OF CONTROLS AND REASON

1.

2.

3.

4.

APPENDIX C

COOPER RATINGS

ADJECTIVE RATING	NUMERICAL RATING	DESCRIPTION	PRIMARY MISSION ACCOMPLISHED	CAN BE LANDED
	1	Excellent, includes optimum	yes	yes
Satisfactory (Normal Operation)	2	Good, pleasant to fly	yes	yes
	3	Satisfactory, but with some mildly unpleasant characteristics	yes	yes
	4	Acceptable, but with some unpleasant characteristics	yes	yes
Unsatis-factory (Emergency Operation)	5	Unacceptable for normal operation	doubtful	yes
	6	Acceptable for emergency condition only	doubtful	yes
	7	Unacceptable even for emergency condition	no	doubtful
Unacceptable (No Operation)	8	Unacceptable, dangerous	no	no
	9	Unacceptable, uncontrollable	no	no
Unprintable	10	%$#@%$#@%$#@%$#	Did not get back report	

APPENDIX D

RESULTS OF EVALUATIONS

Pilot Number	Movable Deck Mounted Stick	Movable Hand Control Stick	Fixed Deck Mounted Stick	Fixed Hand Control Stick
	(time in seconds out of maximum possible of 180)			
1	125.5	151.7	156.0	159.2
2	135.9	142.1	152.9	160.9
3	133.6	127.8	154.6	140.8
4	128.6	131.7	160.4	160.7
5	139.1	141.2	151.2	153.4
6	162.5	162.4	167.0	160.5
7	136.8	134.0	152.1	122.0
8	130.2	145.1	156.2	154.3
9	145.2	143.1	157.7	166.6
10	165.9	153.9	157.2	160.3
Average	140.3	143.3	156.5	153.8

APPENDIX E

PILOT BACKGROUND, PREFERENCES AND COOPER RATINGS

Pilot No. and Background Experience		Movable Stick	Movable Hand Stick	Fixed Stick	Fixed Hand Stick
1	Preference	4	2	3	1
MEP	Rating	5	2	3	1
2	Preference	1	4	3	2
HEL	Rating	2	5	4	3
3	Preference	4	3	2	1
SEJ	Rating	4	3	2	1
4	Preference	3	4	1	2
PRI	Rating	3	4	1	2
5	Preference	3	4	2	1
MEP	Rating	4	4	3	2
6	Preference	3	4	1	2
MEP	Rating	5	8	3	5
7	Preference	2	3	1	4
NON	Rating	-	-	-	-
8	Preference	3	4	1	2
MEP	Rating	5	6	2	2
9	Preference	2	4	3	1
MEJ	Rating	2	5	4	2
10	Preference	1	4	2	3
SEJ	Rating	2	8	4	5

MEP	Multi-Engine Propeller
HEL	Helicopter
SEJ	Single Engine Jet
MEJ	Multi-Engine Jet
PRI	Private Pilot
NON	No Pilot Experience

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13. ABSTRACT

A simulator was constructed with two sets of aircraft controls; one set was movable and one set was rigid. The control output signals were integrated into an analog computer circuit to provide the desired aerodynamic characteristics. A repeatable, random input voltage to an oscilloscope was used as a basis for a tracking exercise in which the test subject, by manipulation of the control stick, attempted to cancel the random signal. A scoring method was devised which utilized an electronic counter and signal comparator to evaluate pilot performance with each of the four control sticks.

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